# Destruction of LP XM46 Using Molten Salt

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EXECUTIVE SUMMARY

 The preliminary experimental work done on the destruction of the
liquid gun propellant LP XM46 using the Molten Salt Destruction
(MSD) Process at the Lawrence Livermore National Laboratory
(LLNL) for the U.S. Army is described in this report.

The current methods of disposal of large quantities of high explosives
(HE), propellants and wastes containing energetic materials by open
burning or open detonation (OB/OD), or by incineration, are becoming
undesirable. LLNL is developing MSD as an alternative to OB/OD and
incineration of energetic materials.

A series of 24 continuous experimental runs were made wherein a
solution of LP XM46 and water, along with air, were injected into a
bed of molten salt comprising the carbonates of sodium, potassium
and lithium.

- LP XM46 can be safely and completely destroyed in a bed of
molten salt at temperatures well below those needed for
incineration.

- Under optimum operating conditions, less than 1% of the chemically
bound nitrogen in the LP XM46 is converted to NOx, and less than 1%
carbon is converted to CO.

- We have developed a tentative mechanism for the combustion of
XM46 in molten salt.

INTRODUCTION

The Lawrence Livermore National Laboratory (LLNL) is developing methods for the safe and environmentally sound destruction of energetic materials (high explosives (HE) and propellants). Open burn/open detonation (OB/OD) is currently the most common method for destroying excess energetic materials and energetic material-containing wastes. Public concerns and increasingly stringent environmental regulations are steadily increasing the cost of OB/OD of energetic materials. OB/OD may be banned in the near future because it is difficult to monitor and control. Incineration is another possible method of destruction for energetic materials but is facing increased opposition due to negative public perception. The cost to license incinerators is rising steadily due to more stringent controls and permitting delays. Environmentally acceptable alternatives to incineration and OB/OD will have to be developed to destroy energetic materials when recycling/reusing are not feasible.

The Molten Salt Destruction (MSD) Process has been demonstrated for the destruction of HE and HE-containing wastes(1,2,3). MSD has been used by Anti-Pollution Systems (4), and by Rockwell International (5), to destroy hazardous wastes. The destruction of energetic material waste is accomplished by introducing it, together with oxidant gases, into a crucible containing a molten salt, such as sodium carbonate, or a suitable mixture of the carbonates, chlorides or sulfates of sodium, potassium, lithium and calcium. The temperature of the molten salt can be varied between 400° to $900^{o}C$. The relatively high thermal inertia of the melt resists changes in temperature resulting from sudden changes in the feed or heat transfer. The organic components of the waste react with oxygen to produce carbon dioxide, nitrogen and steam. The inorganic components, in the form of "ash", are captured in the molten salt bed as a result of wetting and dissolution of the ash. Halogenated hydrocarbons in the waste (which may be present as a result of halogenated solvents in the waste, or as a result of certain halogenated binders for the HE) generate acidic gases such as hydrogen chloride during the pyrolysis and combustion processes occurring in the melt. These are scrubbed by the alkaline carbonates, producing steam and the corresponding salt, such as sodium chloride. The off-gases from the process are sent through standard off-gas clean-up processing (such as bag- or HEPA filters) before being released to the atmosphere. At the end of the process runs, the salt is separated into carbonates, non-carbonate salts, and

ash. The carbonates are recycled to the process, and the stable salts are disposed of appropriately.

LLNL has built a small-scale (7.5 kg of salt) unit to test the destruction of energetic materials using the MSD process as described in detail later in this report (Figures 1 and 2). The initial unit operated in a pulsed mode, wherein between 10-20 g of the feed was injected into the crucible in a few minutes, followed by several minutes of purging with air. This unit was later modified to accept continuous feed. The experiments described in this report were done in the continuous mode. In addition to LP XM46, we have destroyed the high explosives summarized in Table 1.

Table 1. Incomplete oxidation levels of C and N of explosives in MSD.

Explosive[a]	$\%C \rightarrow CO$	$\%N \rightarrow NO$	Throughput (kg/h)	Form
RDX	0.035	0.05	1.8	Neat powder
HMX	0.035	0.11	1.4	Neat powder
TNT	0.006	0.45	0.50	Neat powder
Explosive D	0.028	0.18	0.49	Neat powder
Comp B-3	0.051	0.09	1.0	Powder
LX-10	0.029	0.019	0.99	Machined part
LX-16	0.064	0.14	1.3	Molding powder
LX-17	0.029	0.20	0.69	Machined part
PBX-9404	0.09	0.25	0.3	Machined part
LP XM46	0.11	0.58	2.6	Diluted solution

[a] **RDX = Hexahydro-1,3,5-trinitro-1,3,5-triazine.**
HMX = Octahydro-1,3,5,7-tetranitro- 1,3,5,7-tetrazocine.
TNT = 2,4,6-Trinitrotoluene.
Explosive D = Ammonium picrate.
Comp B-3 = 60% RDX/40% TNT).
LX-10 = HMX/Viton[DuPont].
LX-16 = PETN(2,2-bis[{nitoxy}methyl]-1,3-propanediol dinitrate)/FPC 461 [Firestone].
LX-17 = TATB(2,4,6-trinitro-1,3,5-benzenetriamine)/Kel F [3M].
PBX-9404 = HMX/tris(2-chloroethyl)phosphate/nitrocellulose.
LP XM46 = Hydroxyammonium nitrate, triethanolammonium nitrate, and water.

Safety is a major consideration in any process where high explosives or wastes containing high explosives are destroyed. In addition to LP XM46, we have successfully and safely destroyed water slurries of 35 weight percent HMX, RDX, PETN and TATB. The water, in addition

to keeping the HE concentration to a safe dilution level, provides a vehicle for pumping the HE.

A typical HE, such as HMX, contains sufficient oxygen to propagate a steady back burn without any additional oxygen. To reduce the probability of this, we developed a special nozzle design, shown in Figure 3. The key features of the nozzle are side injection of the feed into the crucible, external cooling of the feed, and introduction of a large volume of gas, such as nitrogen or air, as a carrier for the feed. The side injection, coupled with external cooling, keep the feed temperature well below 200° C to minimize spontaneous combustion of the HE. The large volume of inert carrier gas further dilutes the HE, provides a large heat capacity, and keeps the velocity of the feed inside the nozzle relatively high. As a result of all these conditions, the HE decomposes only inside the crucible, and not in the feed nozzle. The high injection velocity also helps maintain a high degree of turbulence and mixing inside the crucible.

Experimental Program

The apparatus used for the experiments described below was originally designed and developed to investigate the applicability of the molten salt destruction process to the destruction of HE and HE-containing wastes. The unit was modified to accommodate LP XM46. The main change made was in the feed system, wherein the old nozzle was replaced by a hypodermic syringe. Figure 1 shows the schematic of the experimental setup used in these experiments.

The crucible (shown in Figure 2) is made of stainless steel, which is stable in the presence of alkali carbonates. The crucible has the dimensions 5.76" inside diameter, 6.63" outside diameter, and 24" length. It is fitted with a flange on the top and a removable injection nozzle, described earlier, on the side. Thermocouples are placed at various locations, including the crucible, the feed nozzle (shown in Figure 3), and the exhaust gas outlet. The coolant gas flow is controlled so as to maintain the feed nozzle temperature under 150°   C before the initiation of liquid feed. The temperature of the nozzle drops to well below 100 °   C after the liquid feed is initiated. Gas sample bottles with manual and solenoid valves are attached to the exhaust line. The whole assembly is placed inside an explosion-proof cell, designed to withstand an explosion of up to 500 g of TNT. Even though the entire experiment can be performed remotely, 33% aqueous solution of LP XM46 was not considered to be explosive or

flammable, and all the experiments detailed here were conducted as manned operations. The experimental data were continuously logged on a computer.

To start an experiment, a measured amount of salt is introduced into the crucible from the top, and the top flange is secured. The sample bottles are evacuated, and the vacuum valves are closed off. The sample bottles are now ready to accept samples. A solution of LP XM46 and water is made and kept ready to be pumped into the feed tube. The nozzle coolant gas is turned on to keep the feed nozzle cool. The heaters are switched on, and data logging is initiated. Once the salt approaches its melting point, the carrier gas in the nozzle is turned on to prevent molten salt from entering the feed nozzle. When the temperature of the melt reaches a desired value (between 500° C to 750° C in our runs), the system is ready for accepting the energetic waste.

The waste to be treated is injected in to the crucible through the side nozzle described earlier. The oxidant gases, if needed, are introduced through the tube near the center of the crucible (No additional oxygen is necessary for LP XM46). The gaseous product of the crucible is sent to the vent as shown in Figure 1. Grab gas samples were taken during the experiments, and analyzed using a gas chromatograph and a mass spectrometer (GC/MS), as well as an on-line IR sensor for CO and NO for runs 1-6 and 19-24. Table 2 shows the details of the runs made with LP XM46 under various operating conditions. Gas samples were collected at various intervals after the on-line gas analysis meters indicated a constant reading.

A salt sample is withdrawn from the crucible at the end of the final run, and analyzed for traces of the energetic material, such as the constituents of LP XM46. The heaters are then shut off, and the unit is allowed to cool. The entrained gas, the coolant gas and the oxidant gas are continued until the salt freezes, at which time the gas flows are shut off.

Results and Discussion

We have completed 24 separate runs with LP XM46 in the 7.5 kg molten salt unit. The experimental details of these runs are summarized in Table 2. We varied temperature between 500 and

750°C, feed rate between 2 and 15 g/min. and the oxygen content of the driver gas from 0 to 5 times stoichiometric.

At higher temperatures the amount of CO, unburnt hydrocarbons, and hydrogen are all reduced. This trend is expected due the increased rate of combustion at higher temperatures. These data show that gaseous emissions are lower at higher salt temperatures. We were limited to a 750° C operating temperature due to the materials of construction of the crucible. Extrapolation of these results suggests that emissions may drop further at temperatures of 800 or 850° C.

Figure 4 graphically displays the CO emission data that show the reduction in CO emissions at higher temperatures, but an unexpected reduction in emissions with increased feed rate. It is not known why the production of CO should decrease with increased feed rate, but this is a general trend observed with all energetic materials tested to date in the 7.5 kg MSD unit. More predictably, higher feed rates produce larger amounts of unburnt hydrocarbons and hydrogen (Table 2).
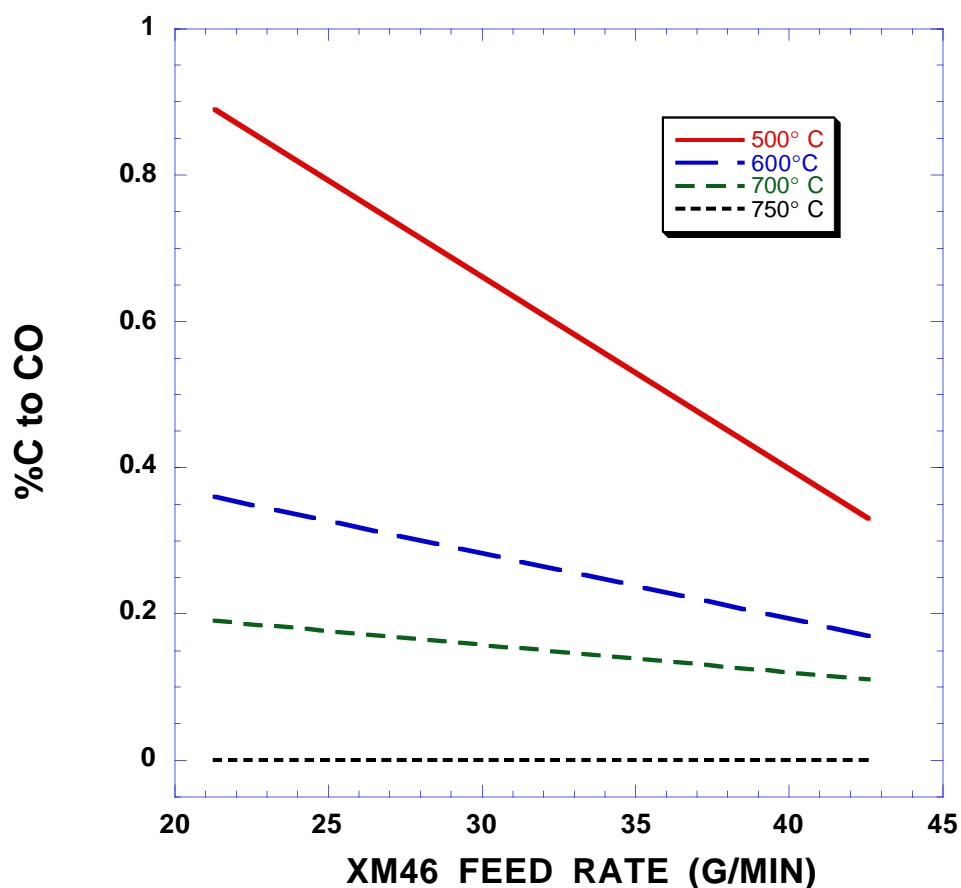
Figure 4. Conversion of feed carbon in XM46 to CO as a function of MSD temperature and feed rate.

As long at the there is an excess of oxygen present during the destruction process the levels of NO emissions are quite low. Even under the worst conditions (with excess oxygen) the fraction of nitrogen in the feed converted to NOx is less than 1% (Tables 2 and 3). In these experiments NO is the principal NOx species and NO_2 and N_2O) could not be measured without incorporation a FT-IR spectrometer.

Table 3: Summary of NO emissions from MSD of LP XM46

Temp (°C)	Feed rate 0.33 kg/h	%N in LP XM46 $\Rightarrow$ NO 0.66 kg/h
500	0.32	0.56/0.24
600	0.49/0.40	0.69
700	0.38/0.81/0.58	0.51/0.62/0,64
750	0.91	0.46

The effect of reducing, neutral and oxidizing conditions under low throughputs at 650° C was examined in runs 7 through 18 and 23 to 24. Since LP XM46 does not need any external oxygen for complete combustion, the addition of the driver air automatically creates oxidizing conditions (runs 7-8, and 13-18). Replacement of the driver air with nitrogen creates neutral conditions (runs 9, 10, 23, 24). Reducing conditions were obtained by the addition of a small amount of isopropanol to the LP XM46, and replacing the driver air with nitrogen (runs 11-12). Figure 5 shows that the NOx fraction shows a slight increase (12% to 16%) from reducing to neutral conditions, followed by a large drop (16% to 1%) from neutral to oxidizing conditions. (The CO analyses for runs 7 through 18 showed large amount of scatter, and were not considered reliable.)

Figure 5. Effect of oxidative conditions on NO emissions

%N in XM46 to NO
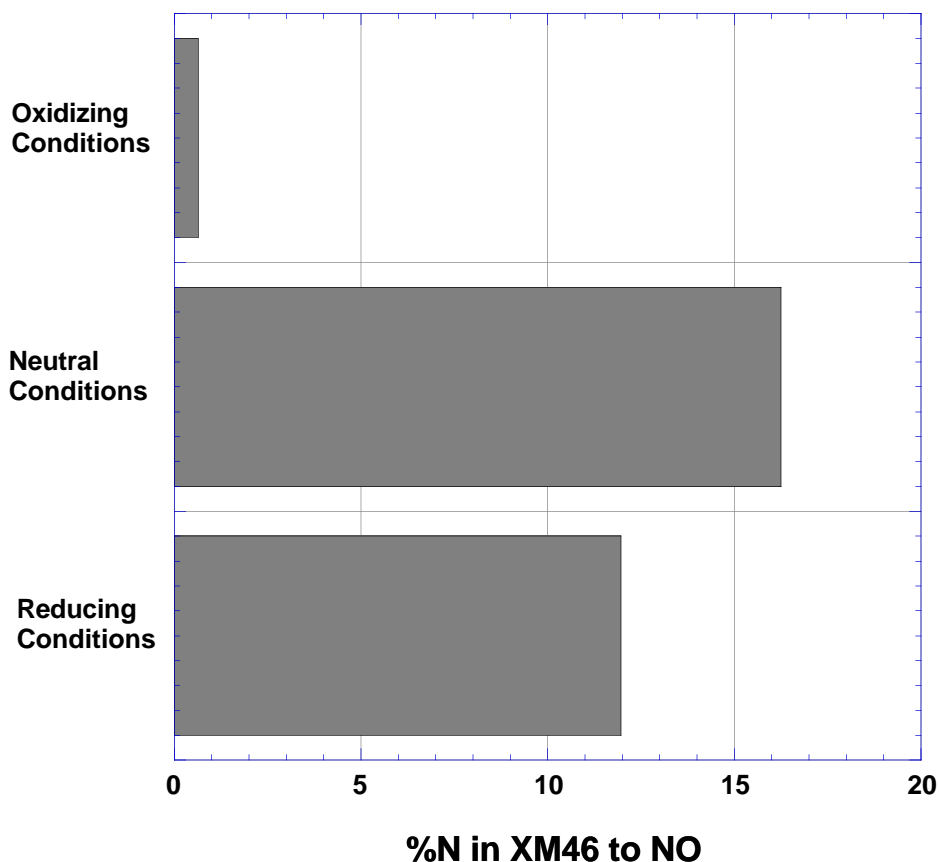
We performed a comparison of MSD with a packed bed reactor[9]. This reactor may be operated as an incinerator with air as the driver gas or as a thermal pyrolyser with nitrogen as the driver gas. These different modes are compared in Table 4. Pyrolysis or combustion under incinerator-like conditions of XM46 produces considerable amounts of NO, as does operation of MSD using nitrogen as the driver gas. However, operation of the MSD unit with air produces lower amounts of NO. Of all of the conditions tested, molten salt destruction of XM46 using air produces the lowest emissions.

Table 4: Comparison of MSD to packed Bed Incineration

		%N $\Rightarrow$ NO
MSD	air, 750°C, 0.66kg/h	0.46
MSD	nitrogen, 750°C, 0.66kg/h	32
Packed bed incineration	air, 560°C, 5.1 kg/h	48
Packed bed incineration	nitrogen, 560°C, 2.5kg/h	12

We also analyzed the condensed water from the cold trap, as shown
in Table 5. At 500°C the ammonia concentration in the condensate
varied between 1200 and 1800 ppm, depending on feed rate. As the
temperature was increased to 600°C the ammonia dropped in half
and then to 30 to 70 ppm at 700°C. It appears that ammonia is
incompletely combusted below 600°C, but is nearly completely
combusted by 700° C. The pH of the condensate varied greatly from
less than 1 to almost 10. The condensate was expected to be slightly
acidic due to the presence of dissolved carbon dioxide. This, of
course, is moderated by salt entrainment, and subsequent carry-over
into the condensate vessel. There was a higher concentration of both
sodium and potassium in runs with higher feed rates (runs 2, 4, and
6) This may be due to greater entrainment of the molten salt by the
higher product gas velocity in the high feed runs.

Table 5: Analyses of the condensate from the cold trap

 Condensate values in mg/L

Run Numbers	1	2	3	4	5	6
Nitrite	1074	1516	1776	1789	2425	ND
Nitrate	699	1463	2324	3368	753	7961
Sodium	252	873	361	613	405	709
Potassium	449	1855	702	1258	900	1413
Ammonia	1260	1820	540	800	32	66
pH	9.34	9.79	4.54	9.13	0.91	4.36
Nitrite/Nitrate	1.54	1.04	0.76	0.53	3.22	
Na/K	0.56	0.47	0.51	0.49	0.45	0.50

We examined the composition of the salt bath after 2.5 L of diluted
LP XM46 had been processed. The concentration of nitrate in the
bed was 4.50% and of nitrite 0.42%. Thus, roughly 50% of the nitrate

in the LP XM46 remained in the salt bath after the termination of the run. It is not known why so much nitrate should remain in the salt bath under these conditions. This led to the design of another experiment to test the availability of the nitrate in the salt bath to oxidize combustibles.

We began with an unused carbonate salt bath which was analyzed to have no nitrate or nitrite. We then ran LP XM46 to produce a salt bath that was 1.19% nitrate and 0,94% nitrite by weight (Table 6). We then ran a 50:50 mixture of 2-propanol in water at a flow rate of 10 ml/min. for 60 min. (nitrogen driver gas). At the end of this time the salt was analyzed to have no nitrate or nitrite. Clearly the nitrate in the bed is being used to oxidize the propanol. Nitrogen in this case is emitted mainly as NO.

Table 6. Analysis of salt bed after MSD of LP XM46

	Nitrate	Nitrite
Prior to run	ND	ND
After LP XM46	1.19 wt%	0.94 wt%
After 2-propanol	ND	ND

ND = not detected

These experiments provide a little insight into the mechanism of combustion of XM46 in a molten salt bath. The proposed reaction scheme is presented in Figure 6. Organic material in the XM46 may either be oxidized by nitrate in the formulation or oxygen in the driver air. At low nitrate concentrations in the salt bath the rate of oxidation is faster using oxygen than nitrate, so nitrates slowly builds up in the salt bath. We suspect that the nitrate concentration builds up for a while and then stabilizes at a reasonable low value, but we have not experimentally verified this.

In support of this hypothesis we have shown that the residual nitrate/nitrite in the salt bath may be readily removed by the addition of 2-propanol which serves as a reducing agent for the nitrate/nitrite. Under oxygen-poor conditions nitrate in the salt bath slowly decomposes to produce NO, NO_2 and O_2. Nitrate/nitrate also react with fuel to produce NO.

We suspect that under a constant feed of XM46 in the presence of excess oxygen (air) a steady state concentration of nitrate will exist in the salt bath. This will continue to produce low NO due to the presence of fuel and oxygen. This hypothesis needs to be investigated and is the subject of the next series of experiments.

Figure 6. Postulated MSD reaction chemistry

$$C\ (TEAN) + O_2 \rightarrow CO_2$$

$$C\ (TEAN) + NO_3^- \rightarrow N_2 + CO_2$$

$$HAN \leftrightarrow HNO_3 + NH_2OH$$

$$HNO_3 + Na_2CO_3 \rightarrow NaNO_3 + H_2O + CO_2$$

$$NaNO_3 + C(2\text{-propanol}) \rightarrow N_2 + Na_2CO_3$$

$$NaNO_3 \rightarrow NaNO_2 + O_2$$

$$NaNO_2 \rightarrow NO + NO_2 + Na_2O$$

$$Na_2O + CO_2 \rightarrow Na_2CO_3$$
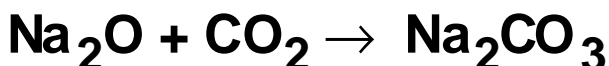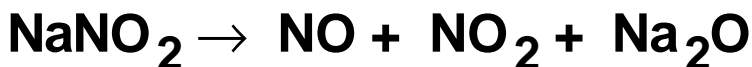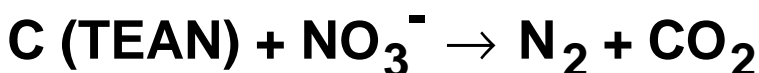
Conclusions and Future Work

The major conclusions from this work are:

- LP XM46 can be safely and completely destroyed in the molten salt bath.

- Under optimum operating conditions, less than 1% of the chemically bound nitrogen in the LP XM46 is converted to NOx, and less than 1% carbon is converted to CO.

There exist, however, a number of technical uncertainties:

- Do the nitrate/nitrite concentrations reach a steady state ? If a steady state is reached, how long does it take to reach it under the optimal operating conditions?

- Will the CO- and Nox- emissions remain low with further scale-up ?

- Can the bed be regenerated without high NO emissions?

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Appendix 1

Results of the Experiments and Data Analysis

The experimental data obtained during the course of this work is summarized in Tables 1 and 2. Table 1 shows the experimental conditions and off-gas analyses. Table 2 shows the composition of the condensate from the cold trap.

Explanation of the terms used in Table 1

Run Number: ID number for the run Temp, C: Salt temperature, in degrees Celsius Feed rate: measured feed rate, ml/min Density: calculated density of the feed solution Feed rate, g/min: product of volumetric feed rate and density

The next three rows represent calculated values of the concentrations of TEAN, HAN and water in units of g per gram of solution. These values are in turn used to calculate the absolute flow rates of these three components in units of g/min. The next row represents the flow rate of LGP into the molten salt unit, in units of g/min.

Salt inventory: Weight of salt in the crucible, kg

Space velocity: Flow rate of LGP in units of g/hr divided by grams of salt in the vessel

The next row indicates whether the experiments were conducted in (nominal) reducing, neutral or oxidizing conditions. Most experiments are under oxidizing conditions because the driver gas used in the nozzle was air. Runs 9 and 10 are under neutral conditions because the driver gas used was nitrogen. To obtain reducing conditions, such as in runs 11 and 12, small amounts of isopropanol were added to the feed, and nitrogen was used as the driver gas.

The next 10 rows contain the results of gas analyses on the off-gas. They are expressed in volume (or mole) percents. C2, C3 and C4 represent all hydrocarbon compounds with carbon chain lengths of 2, 3 and 4 respectively.

The next two rows represent maximum possible and actual ratios of NO in the off-gas to the total carbon in the off-gas. If ALL the N in the LGP is converted to NO, this ratio will be 2.67. Thus, the ratio of actual to maximum represents the fraction of the chemically bound nitrogen in the LGP that is converted to NO. This ratio is referred to as Nfr_1.

The next row shows the percentage of the carbon in the LGP that is converted to CO.

For run numbers 1 through 6, for which reliable air flow data are available, we performed the NOx fraction calculations based on the total product gas flow and the composition of the NO in the product gas. Once again, we calculated the NO fraction, referred to as Nfr_2. Finally, the ratio of Nfr_2 to Nfr_1 provides a comparison of the two methods of calculating the NO fraction.

Table 2: Analysis of LP XM46 data

Run Number	1	2	3	4	5	6
Temp, ^{o}C	500	500	600	600	700	700
feed rate in ml/min	18.5	37	18.5	37	18.5	37
density, g/ml	1.15	1.15	1.15	1.15	1.15	1.15
feed rate, g/min	21.275	42.55	21.275	42.55	21.275	42.55
g TEAN/g solution	0.07	0.07	0.07	0.07	0.07	0.07
g HAN /g solution	0.22	0.22	0.22	0.22	0.22	0.22
g H2O /g solution	0.71	0.71	0.71	0.71	0.71	0.71
TEAN g/min	1.50	3.01	1.50	3.01	1.50	3.01
HAN g/min	4.77	9.53	4.77	9.53	4.77	9.53
H2O g/min	15.01	30.01	15.01	30.01	15.01	30.01
LP XM46 g/min	7.84	15.68	7.84	15.68	7.84	15.68
g mole/min TEAN	0.0071	0.0142	0.0071	0.0142	0.0071	0.0142
Driver air flow						
SCFH	25	25	25	25	25	25
liter/min	11.8	11.8	11.8	11.8	11.8	11.8
off gas, gmol/min						
from LP XM46	0.3000	0.6001	0.3000	0.6001	0.3000	0.6001
from water	0.8336	1.6673	0.8336	1.6673	0.8336	1.6673
air	0.5268	0.5268	0.5268	0.5268	0.5268	0.5268
total	1.6605	2.7941	1.6605	2.7941	1.6605	2.7941
total, dry	0.6261	0.7254	0.6261	0.7254	0.6261	0.7254
salt inventory,kg	6.40	6.40	6.40	6.40	6.40	6.40
space velocity g LP XM46/hr/g salt	0.07	0.15	0.07	0.15	0.07	0.15
% stoich O2 used	>100	>100	>100	>100	>100	>100
Gas Comp (dry basis) in vol %						
N2	79.00	80.65	79.31	76.66	77.94	76.28
O2	15.27	12.20	14.49	10.58	13.39	8.58
Ar	0.85	0.87	0.88	0.84	0.88	0.83
CO2	0.93	2.39	3.52	7.71	7.17	12.32
CO	0.01	0.01	0.01	0.01	0.01	0.01
H2	0.20	0.71	0.15	0.47	0.00	0.05
CH4						
C2	0.09	0.79	0.02	0.07	0.00	0.00
C3						
C4						
NO	0.03	0.08	0.07	0.19	0.08	0.19
NO/C						
maximum	2.67	2.67	2.67	2.67	2.67	2.67
actual	0.02	0.02	0.02	0.02	0.01	0.02
%N to NO (Nfr_1)	0.88	0.75	0.69	0.90	0.42	0.58
%C to CO	0.89	0.33	0.36	0.17	0.19	0.11
g moles NOx/min						
max possible	0.11	0.23	0.11	0.23	0.11	0.23
actual	0.00	0.00	0.00	0.00	0.00	0.00
%N to NO (Nfr_2)	0.14	0.26	0.36	0.60	0.45	0.61
Nfr_2/Nfr_1	0.16	0.34	0.53	0.67	1.06	1.05

Table 2 (continued): Analysis of LP XM46 data

Run Number	7	8	9	10	11	12
Temp, ^{o}C	650	650	650	650	650	650
feed rate in ml/min	5	5	5	5	5	5
density, g/ml	1.15	1.15	1.15	1.15	1.15	1.15
feed rate, g/min	5.75	5.75	5.75	5.75	5.75	5.75
g TEAN/g solution	0.07	0.07	0.07	0.07	0.07	0.07
g HAN /g solution	0.22	0.22	0.22	0.22	0.22	0.22
g H2O /g solution	0.71	0.71	0.71	0.71	0.71	0.71
TEAN g/min	0.41	0.41	0.41	0.41	0.41	0.41
HAN g/min	1.29	1.29	1.29	1.29	1.29	1.29
H2O g/min	4.06	4.06	4.06	4.06	4.06	4.06
LP XM46 g/min	2.12	2.12	2.12	2.12	2.12	2.12
g mole/min TEAN						
Driver air flow						
SCFH						
liter/min						
off gas, gmol/min						
from LP XM46						
from water						
air						
total						
total, dry						
salt inventory,kg	6.40	6.40	6.40	6.40	6.40	6.40
space velocity	0.02	0.02	0.02	0.02	0.02	0.02
g LP XM46/hr/g salt						
% stoich O2 used	>100	>100	100	100	<100	<100
Gas Comp (dry basis) in vol %						
N2	73.78	72.64	85.71	85.73	84.35	84.35
O2	12.20	12.11				
Ar	0.83	0.82				
CO2	13.01	14.37	8.05	7.83	7.85	7.94
CO			1.34	1.34	1.89	1.90
H2			0.63	0.63	1.32	1.24
CH4			0.12	0.12	0.80	0.75
C2			0.09	0.09	0.22	0.23
C3					0.02	0.02
C4					0.01	
NO	0.18	0.10	4.05	4.25	3.52	3.56
NO/C						
maximum	2.67	2.67	2.67	2.67	2.67	2.67
actual	0.01	0.01	0.42	0.45	0.32	0.32
%N to NO (Nfr_1)	0.52	0.26	15.69	16.81	11.90	12.02
%C to CO	0.00	0.00	13.83	14.15	17.05	17.11
g moles NOx/min						
max possible						
actual						
%N to NO (Nfr_2)						
Nfr_2/Nfr_1						

Table 2 (continued): Analysis of LP XM46 data

Run Number	13	14	15	16	17	18
Temp, $^\circ$C	650	650	650	650	650	650
feed rate in ml/min	5	5	10	10	10	10
density, g/ml	1.15	1.15	1.15	1.15	1.15	1.15
feed rate, g/min	5.75	5.75	11.5	11.5	11.5	11.5
g TEAN/g solution	0.07	0.07	0.07	0.07	0.07	0.07
g HAN /g solution	0.22	0.22	0.22	0.22	0.22	0.22
g H2O /g solution	0.71	0.71	0.71	0.71	0.71	0.71
TEAN g/min	0.41	0.41	0.81	0.81	0.81	0.81
HAN g/min	1.29	1.29	2.58	2.58	2.58	2.58
H2O g/min	4.06	4.06	8.11	8.11	8.11	8.11
LP XM46 g/min	2.12	2.12	4.24	4.24	4.24	4.24
g mole/min TEAN						
Driver air flow						
SCFH						
liter/min						
off gas, gmol/min						
from LP XM46						
from water						
air						
total						
total, dry						
salt inventory,kg	6.40	6.40	6.40	6.40	6.40	6.40
space velocity	0.02	0.02	0.04	0.04	0.04	0.04
g LP XM46/hr/g salt						
% stoich O2 used	>100	>100	>100	>100	>100	>100
Gas Comp (dry basis in vol %						
N2	75.23	74.09	72.27	72.68	76.57	77.68
O2	13.10	13.68	7.68	8.01	17.75	18.35
Ar	0.87	0.86	0.81	0.83	0.90	0.92
CO2	10.37	10.92	18.51	17.68	4.38	3.01
CO	0.28	0.37	0.45	0.47	0.35	
H2						
CH4			0.13	0.03		
C2			0.03			
C3						
C4						
NO	0.14	0.07	0.11	0.30	0.04	0.04
NO/C						
maximum	2.67	2.67	2.67	2.67	2.67	2.67
actual	0.01	0.01	0.01	0.02	0.01	0.01
%N to NO (Nfr_1)	0.48	0.24	0.22	0.61	0.28	0.49
%C to CO	2.63	3.28	2.35	2.59	7.40	0.00
g moles NOx/min						
max possible						
actual						
%N to NO (Nfr_2)						
Nfr_2						
Nfr_1						

Table 2 (continued): Analysis of LP XM46 data

Run Number	19	20	21	22	23	24
Temp, $^{\circ}$C	700	700	750	750	750	750
feed rate in ml/min	18.5	37	18.5	37	18.5	37
density, g/ml	1.15	1.15	1.15	1.15	1.15	1.15
feed rate, g/min	21.275	42.55	21.275	42.55	21.275	42.55
g TEAN/g solution	0.07	0.07	0.07	0.07	0.07	0.07 g
HAN /g solution	0.22	0.22	0.22	0.22	0.22	0.22 g
H2O /g solution	0.71	0.71	0.71	0.71	0.71	0.71
TEAN g/min	1.50	3.01	1.50	3.01	1.50	3.01
HAN g/min	4.77	9.53	4.77	9.53	4.77	9.53
H2O g/min	15.01	30.01	15.01	30.01	15.01	30.01
LP XM46 g/min	7.84	15.68	7.84	15.68	7.84	15.68 g
mole/min TEAN	0.0071	0.0142	0.0071	0.0142	0.0071	0.0142
Driver air flow						
SCFH	87.3	87.3	87.3	88.3	67.8	67.8
liter/min	41.2	41.2	41.2	41.2	32.0	32.0
off gas, gmol/min						
from LP XM46						
from water						
air						
total						
total, dry						
salt inventory,kg	7.5	7.5	7.5	7.5	7.5	7.5
space velocity LP XM46/hr/g salt	0.057	0.11	0.057	0.11	0.057	0.11 g
% stoich O2 used	>100	>100	>100	>100	0	0
Gas Comp (dry basis) in vol %						
N2	78.66	79.99	78.93	79.26	94.68	94.75
O2	18.31	17.88	17.10	16.13	ND	ND
Ar	0.88	0.88	0.88	0.88	0.021	0.025
CO2	2.12	2.21	3.05	3.67	2.30	2.27
CO	ND	ND	ND	ND	0.74	0.33
H2						
CH4						
C2						
C3						
C4						
NO	0.033	0.038	0.073	0.045	2.01	2.25
NO/C maximum	2.67	2.67	2.67	2.67	2.67	2.67
actual	0.016	0.017	0.024	0.012	0.66	0.86
%N to NO (Nfr_1)	0.58	0.24	0.91	0.46	24.7	32.2
%C to CO	ND	ND	ND	ND	24.3	12.7
g moles NOx/min						
max possible						
actual						
%N to NO (Nfr_2)						
Nfr_2 Nfr_1						

Figure 1. Molten salt destruction unit

Figure 2. Details of the crucible
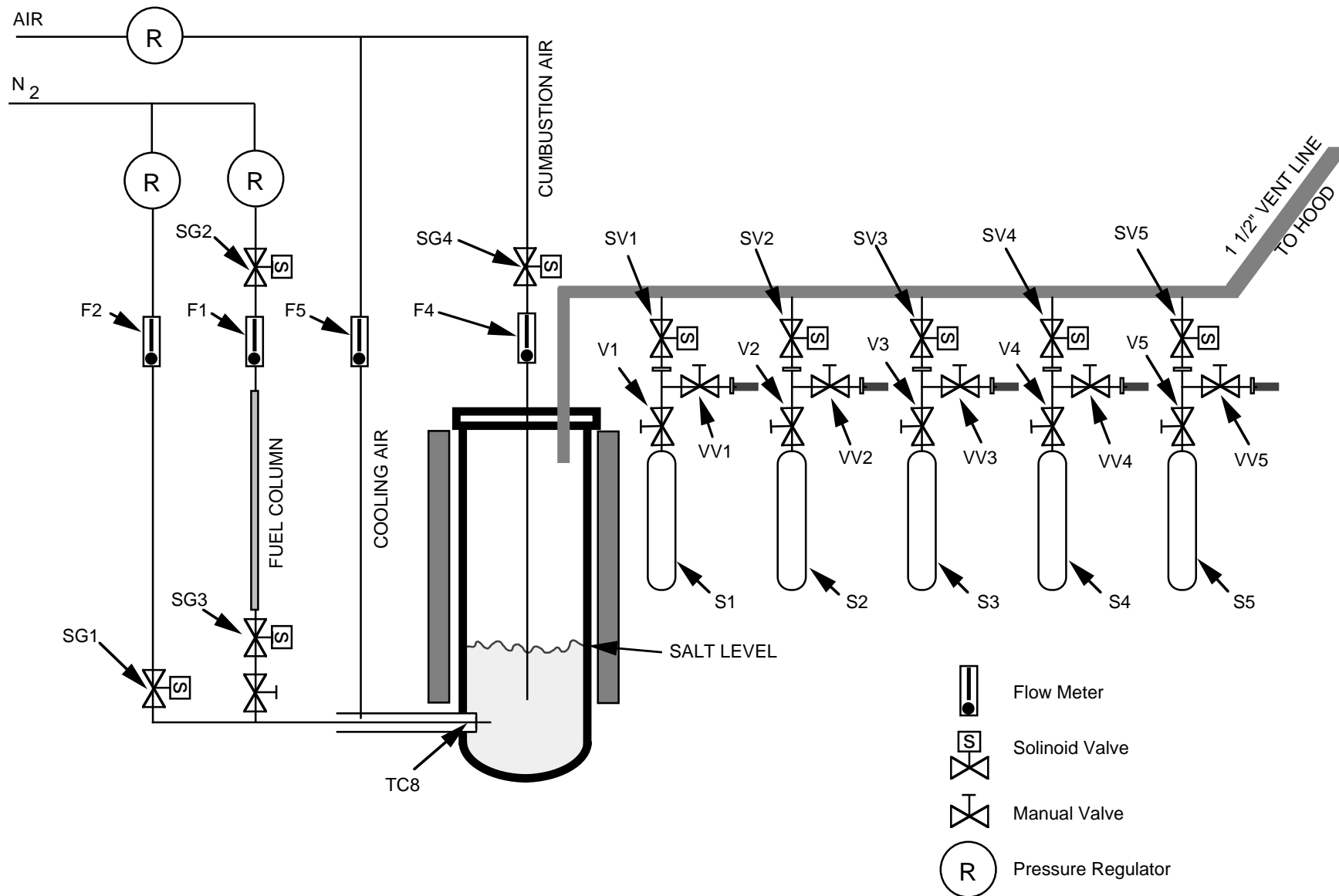
Figure 2. Details of the crucible
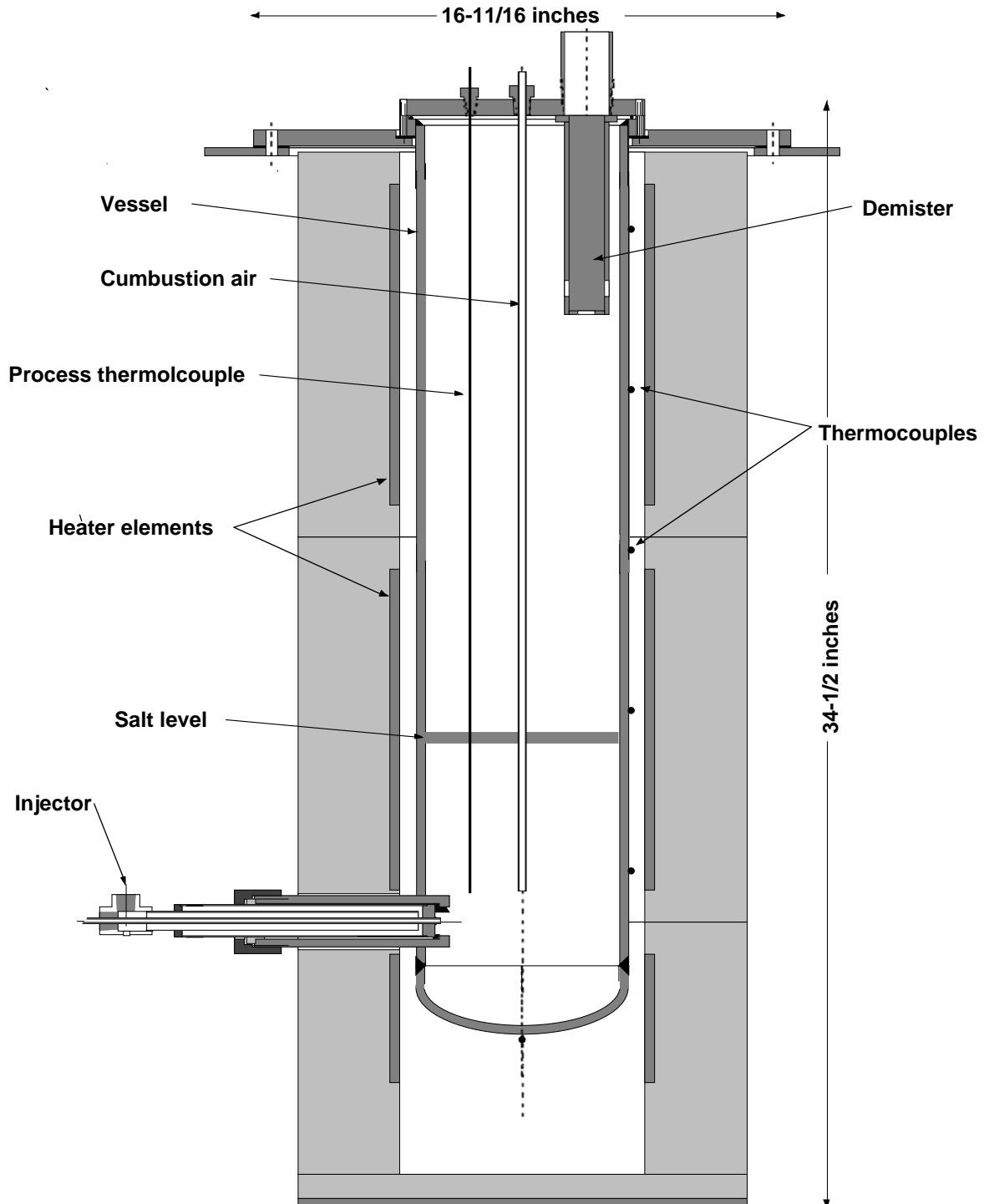
Figure 3. MSD injector nozzle